C-A/AP/#275
May 2007

Run05 Proton Beam Polarization Measurements by pC-Polarimeter (DRAFT)

I. Nakagawa, I. Alekseev, A. Bazilevsky, A. Bravar, G. Bunce, S. Dhawan, K.O. Eyser, R. Gill, W. Haeberli, H. Huang, Y. Makdisi, A. Nass, H. Okada, E. Stephenson, D.N. Svirida, T. Wise, J. Wood, A. Zelenski

Collider-Accelerator Department
Brookhaven National Laboratory
Upton, NY 11973

Run05 Proton Beam Polarization Measurements by pC-Polarimeter (DRAFT)

I. Nakagawa, I. Alekseev, A. Bazilevsky, A. Bravar, G. Bunce, S. Dhawan, K.O. Eyser, R. Gill, W. Haeberli, H. Huang, Y. Makdisi, A. Nass, H. Okada, E. Stephenson, D.N. Svirida, T. Wise, J. Wood, and A. Zelenski

May 1, 2007

Measurements were made using the carbon target polarimeters throughout the 2005 run. Online results based on a normalization from the 2004 Jet calibration[1] (see figure 1) were immediately posted and available to the experiments. During 2005, the carbon measurements were generally made with vertical targets at one location in x (transverse horizontal coordinate), with the intention that the measurement be at the intensity peak in x. Only three dedicated polarization profile measurements were taken, with good statistics in the tails of the intensity distribution. A few scan profile measurements, with equal time at each x or y point (some used a horizontal target) were taken near the end of the 2005 run.

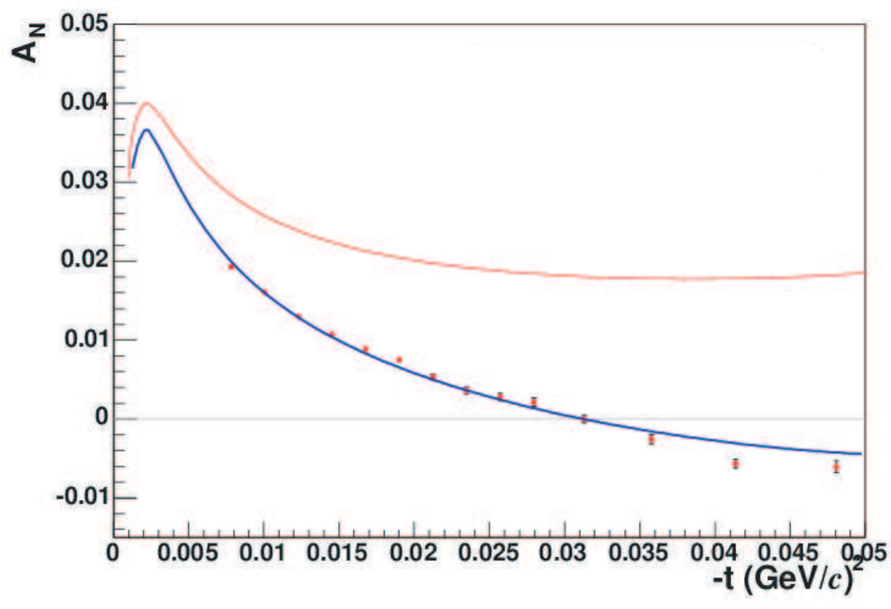

Figure 1: A_N measured during Run04.

Also, throughout the 2005 run the jet target was used[2], at first with both beams on the target simultaneously, then for the remainder of the run (most of it) with one beam at a time on the jet. Oleg Eyser has grouped these measurements into categories: for blue-both beams; 60 bunch mode, 120 bunch mode; for yellow-both beams, 60 bunch mode; 120 bunch mode. Generally these measurements extend across many fills, and the jet did not take data over entire fills. (The jet was stopped for carbon measurements, and sometimes not restarted immediately for example.) The steps to calibrate the carbon measurements with the jet, then to estimate the polarization for the experiments:

1) Through quality checks on the carbon event mode data, eliminate questionable measurements. These Q/A checks do not use the measured polarization values. These checks include the width of the carbon mass peak (problems with WFDs can cause double peaking as shown in Figure2), problems with the energy slope of the data as seein Figure3(a larger slope is observed early in the run when targets were downstream from their correct positions), and poor chi2 for left-right asymmetries measured bunch to bunch (which seems to result from uncollimated beam). See RSC presentation by Itaru[4], 3/21/07.

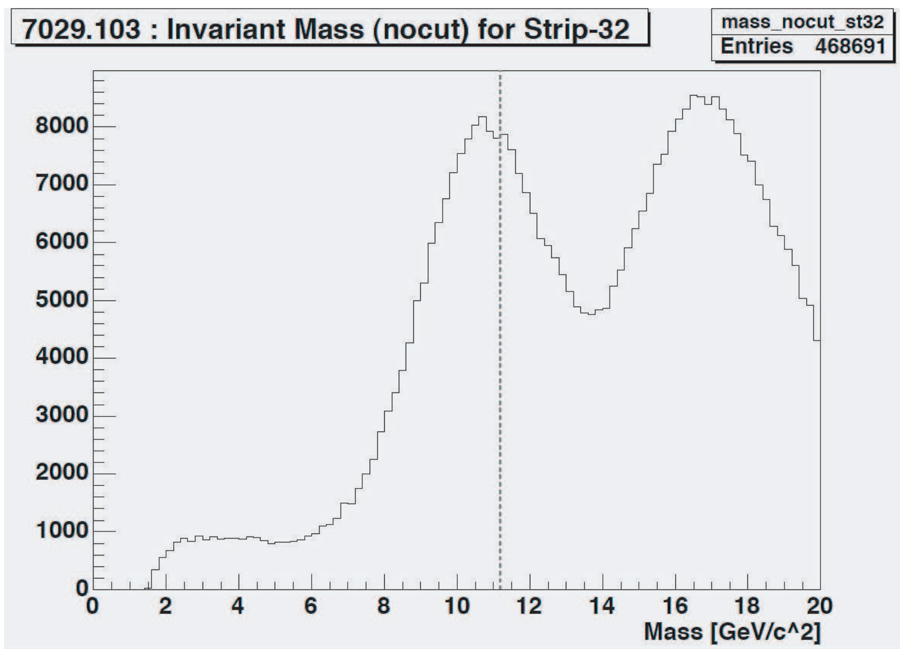

Figure 2: A typical example of double peak caused by electronics failure in WFD module.

2) We found distributions of polarimeter event rates that indicate that the polarization measurements were not always taken near the beam center. Event rates were normalized to take into account different beam intensity and different targets. To the extent that the polarization was not constant across x, measurements away from the beam center (at lower normalized rate) would be biased toward lower polarization than at the center of the beam. A plot of measured polarization vs. event rate showed no correlation for the blue measurements,

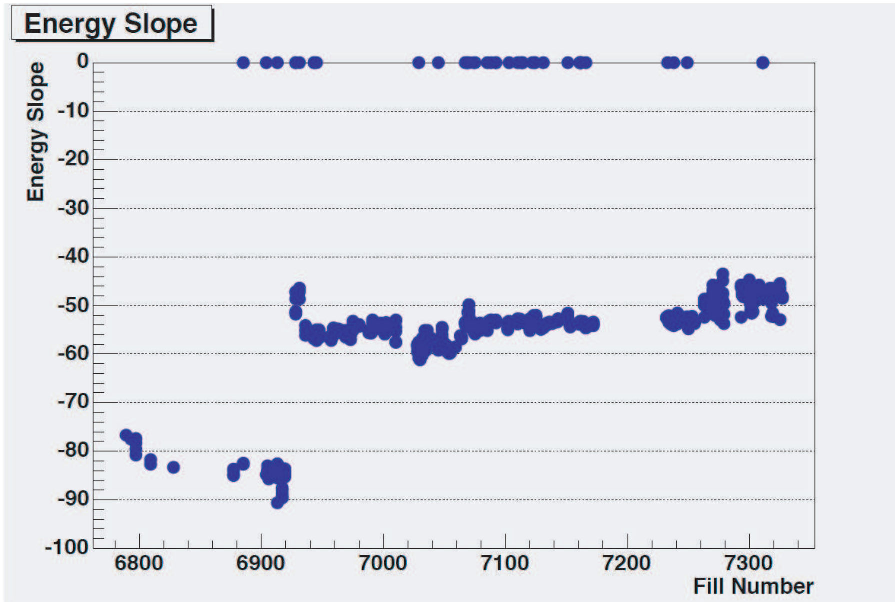

Figure 3: Yelid slope history for blue.

taken over the entire run as shown in Figure4. Also, the one dedicated polarization profile measurement showed little to no polarization change with x as shown in Figure 5. We chose to accept all blue measurements that passed 1).

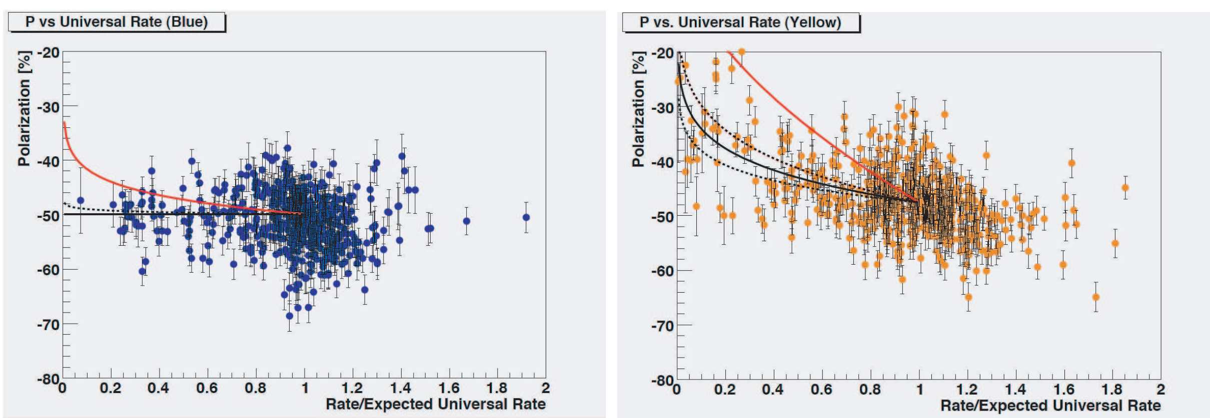

Figure 4: Universal Rate vs. polarization for blue (left) and yellow (right).

The plot of P vs. rate for all yellow measurements showed somewhat lower polarizations for lower rates as shown in Figure 4. Also, the two dedicated polarization profile measurements for yellow showed significant polarization profiles as shown in Figure 6. We described these profiles using gaussian fits, following advice from CAD that generally spin resonances would be expected to result in gaussian profiles. The fits to the measured profiles were

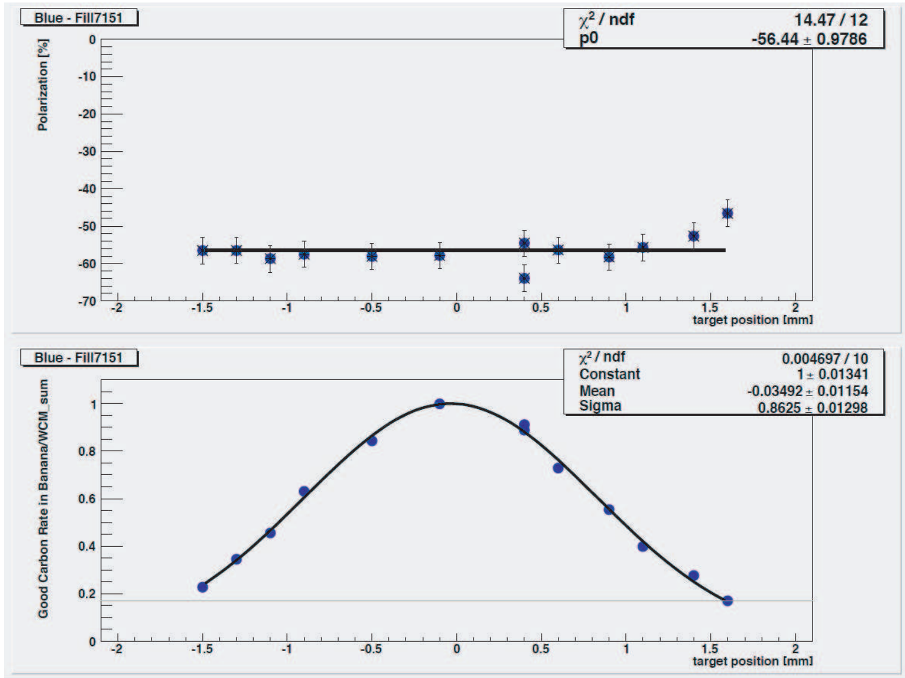

Figure 5: Polarziation (top) and beam intensity (bottom) profiles for blue measured during Fill number 7151.

reasonable. See presentation by Sasha[4] at RSC meeting 3/21/07. We then obtained an average profile that described the P vs. rate plot (presented separately). From this plot, and from the range of "possible" profiles, we decided to use only data for yellow with normalized rates above 50% of the expected rate. We assign a larger uncertainty for the measurements away from the expected rate, but do not "correct" them. The uncertainty assigned is the difference between the fitted profile polarization for that rate and the polarization at the beam center, taken from the gaussian model that describes the P vs. rate data. Note that after we only use measurements with relative rates above 50%, these differences are not large, and there are not so many of these measurements.

3) To normalize with the jet, we decided to obtain averages of the measurements in a fill to obtain a polarization from the pC polarimeter for each fill. This was done by a $(1/uncertainty)^2$, beam-intensity, and time-weighted average of the measurements in a fill that passed 1) and 2). The uncertainty used for each measurement was the statistical uncertainty added quadratically to the polarization profile uncertainty described in 2). See Figure 7. For blue, no profile uncertainty; for yellow, an uncertainty depending on the normalized polarimeter rate. The time weighting was used to average over a fill by assigning a weight for each measurement of the time duration polarization up to the midpoint in time until the next measurement. Thus the measurements with significantly lower rate than the expected rate contribute less to the average polarization of that fill.

The uncertainty for the fill polarization is a quadratic sum of the statistical uncertainty

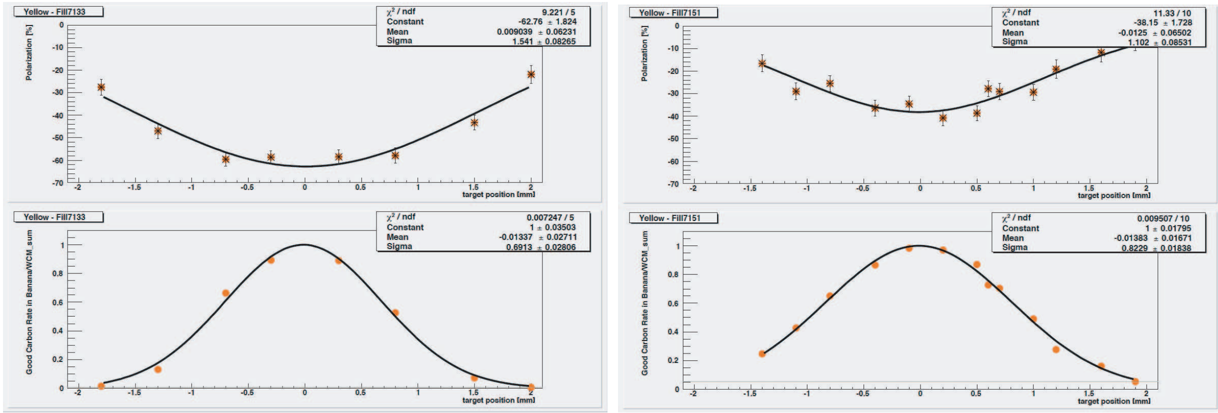

Figure 6: Polarziation (top) and beam intensity (bottom) profiles for blue measured during Fill number 7151.

from the above approach to obtain the average fill polarization, the contribution from observed fluctuations in the energy correction which affects the polarization (1.5% in blue and 1.7% in yellow, in Delta P/P), an uncertainty due to polarization profile (4.3% for blue and 5.7% for yellow in Delta P/P), and an uncertainty that depends on the number of measurements in the fill that were taken away from the beam center. For the latter, blue had no uncertainty for this (no observed polarization profile as seen in Figure 4), and the yellow uncertainty was taken as the difference in fill polarization correcting for these off-center measurements vs. not correcting for them (note: we do not correct the polarizations; this is a method to obtain the uncertainty only). In this way, fills with off-center measurements have larger uncertainties.

4) The average polarizations for three distinct jet measurement periods are then calculated using fill by fill polarization averages ($P_{\rm pC}^{\rm fill}$) derived by the procedure 3). The average $P_{\rm pC}^{\rm fill}$ are weighted by the duration of the jet operation of each fill. If the jet operated for only a small fraction of the fill duration, then the $P_{\rm pC}^{\rm fill}$ of the fill will contribute less to the average polarization of the given jet measurement period.

5) With the estimate of the polarization measured by the vertical target at the center of the beam for a jet measurement period, we then needed to obtain an intensity-weighted average for the polarization, averaged over the x distribution of the beam, in order to compare with the jet measurement. This requires the x polarization profile. Because the vertical target automatically takes an intensity-weighted average over any y polarization profile, the required average is only for the x dimension. Here we use the profiles fitted to the P vs. rate plots, with uncertainties estimated from these fits as indicated by the curves in Figure4. This correction is $P_{\rm pC}^{\rm Iavg} = P_{\rm pC} \times C_{\rm 1X}$, with different $C_{\rm 1X}$ and uncertainty for blue and yellow. This is described separately. The subscript Iavg refers to averaging over the beam intensity distribution, and subscript 1X refers to weighting by the intensity to the power 1, in the x dimension. This correction is referred to as "profile for A_N" and these are global uncertainties. These are 0.5% for blue and 2.2% for yellow, in $\Delta A_N/A_N$.

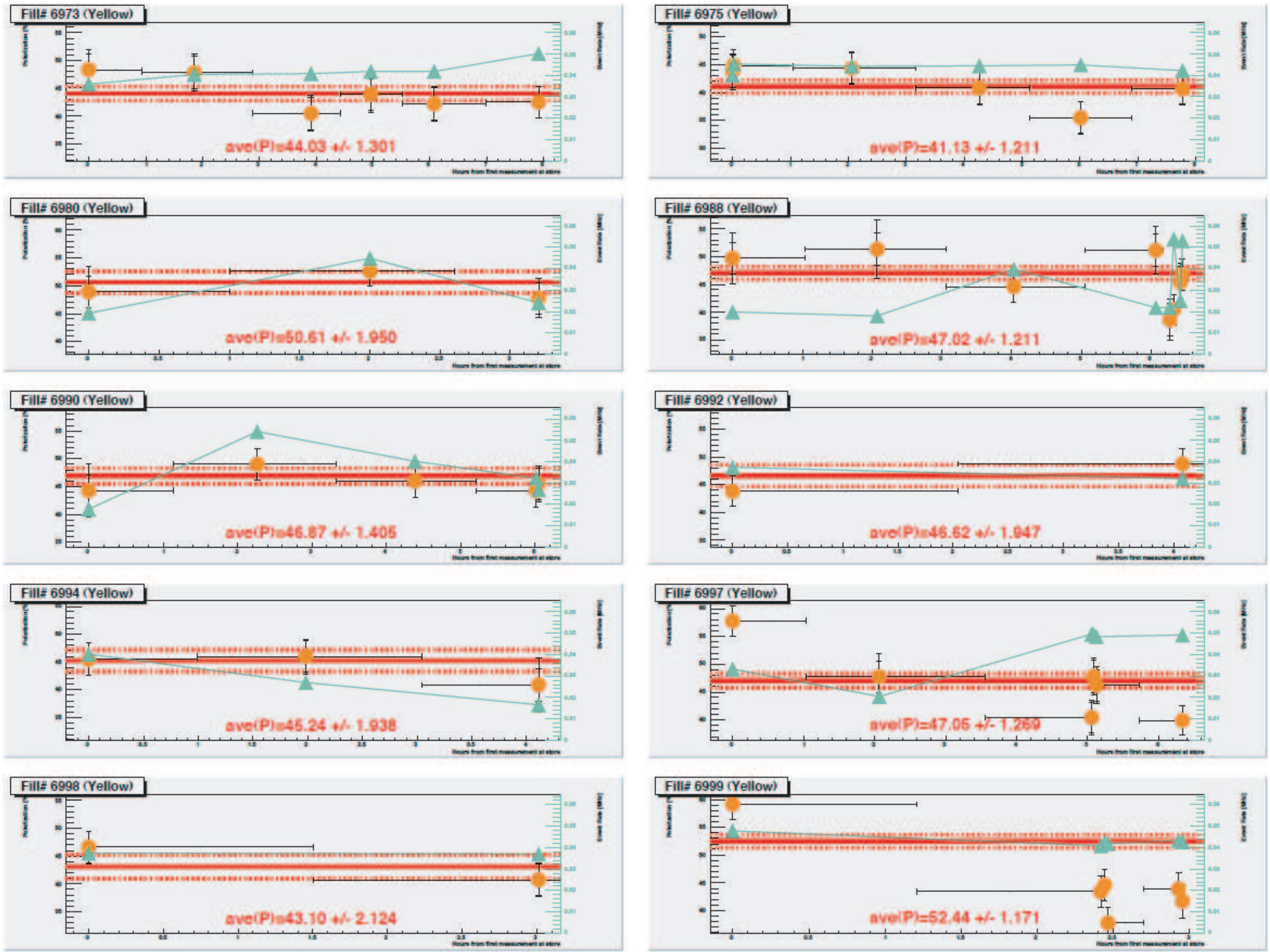

Figure 7: Averaging procedure for multiple polarization measurements in a given fill. The horizontal error bar shows the time weight explained in the main document and the vertical error shows statistical error and total error. The total error is the quadratic sum of the statistical and the profile errors.

6) The agreement between the 2004[3] and 2005 jet calibrations is good, as shown in Figure8 and also as described by Itaru[4] in the RHIC Spin Collaboration meeting of 3/21/07. The results are presented as the new analyzing power and uncertainties for the pC measurements, separately for blue and yellow. (There are global uncertainties for the background and molecular fraction for the jet measurements of the beam polarization, the same and completely correlated for blue and yellow. The calibration is separate and independent for blue and yellow polarimeters, as are the statistical errors and profile uncertainties.)

$$
\begin{aligned}
A_N^{blue2005} &= A_N^{2004} \times \{1.01 \pm 0.031^{a)} \pm 0.029^{b)} \pm 0.005^{c)}\} \\
A_N^{yellow2005} &= A_N^{2004} \times \{1.00 \pm 0.028^{a)} \pm 0.029^{b)} \pm 0.022^{c)}\}
\end{aligned}
$$

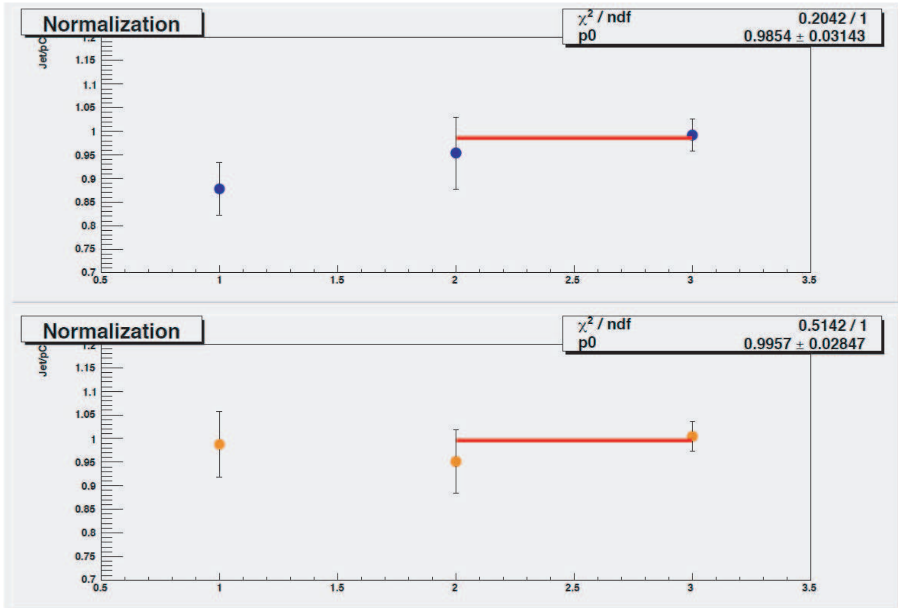

Figure 8: Ratio of average polarzation measured by Jet and pC polarimeters for three different jet operation periods. The first period (both blue and yellow beam simultaneous operation) was excluded from the average.

a) statistical uncertainty from the jet measurement (independent for blue and yellow)
b) systematic uncertainty for jet measurement (correlated for blue and yellow)
c) systematic uncertainty from x profile uncertainty, independent for blue and yellow

7) The last step is to obtain luminosity-weighted polarizations for the experiments. This starts with the pC measurements for each fill, calibrated for 2005, P_{pC}. These are calibrated measurements taken with the vertical targets. Therefore, we must first remove the possible y polarization profile, then reweight by the beam intensity squared (actually by $I_{\mathrm{blue}} \times I_{\mathrm{yellow}}$). This is described separately. The form is

$$\begin{aligned} P_{\mathrm{expt}} &= (P_{\mathrm{pC}}/C_{1\mathrm{Y}}) \times C_{2\mathrm{X}} \times C_{2\mathrm{Y}} \\ &= P_{\mathrm{pC}} \times C_{2\mathrm{X}}/C_{2\mathrm{Y}}. \end{aligned}$$

$C_{1\mathrm{Y}}$ removes the Y polarization profile, and C2X and C2Y weight the X and Y dimensions by intensity^2. These factors are $C_1 = 1/\sqrt{1+R^2}$ and $C_2 = 1/\sqrt{1+1/2R^2}$, with $R = \sigma_I/\sigma_P$. σ_I is the gaussian width of the intensity profile, and σ_P is the gaussian width of the polarization profile. X and Y refer to the horizontal transverse and vertical profiles. We see in the approximation that if the X and Y profiles are the same, there is no correction necessary. This is what we use: our best estimate is that the X and Y profiles are the same.

We only have a few measurements with horizontal targets, scans over the y profile. We do not have a P vs. rate plot for representative measurements over the 2005 run. The profiles that we have, from near the end of the run, show a moderate polarization profile in y for blue and yellow, similar to the fit for the yellow x profile for the run. We have assigned an uncertainty for the y profile that corresponds to the largest uncertainty seen in yellow, for both the blue and yellow y profile. For the uncertainty of the x profile, we use the result described earlier in 5). The result is the largest uncertainties, for "profile for experiment polarization" of 4.0% for blue and 4.1% for yellow. These are global uncertainties, and the uncertainties are uncorrelated.

8) We report to the experiments the fill polarizations as measured with the vertical carbon targets, calibrated for 2005, separately for the STAR and PHENIX/BRAHMS colliding bunches. We also report fill-to-fill uncertainties which are uncorrelated. Finally we report the correction factor to weight the polarizations by luminosity, with its uncertainty (this factor is 1.0). This uncertainty is global and uncorrelated between blue and yellow. The calibration A_N includes global correlated and uncorrelated uncertainties (see 6)). These are presented in separate tables.

An example to obtain the polarization for a set of fills from the distributed tables:

$$P = \sum_{\text{fills}}[P_{\text{fill}}/(\sigma^2_{\text{tot}})]/\sum_{\text{fills}}[1/(\sigma^2_{\text{tot}})] \tag{1}$$

The uncertainty is

$$\Delta P = \Delta P_{\text{fills}} \pm P \times (\Delta^{\text{stat}}_{\text{Jet}} \pm \Delta^{A_N}_{\text{profile}} \pm \Delta^{\text{exptP}}_{\text{profile}} \pm \Delta^{\text{syst}}_{\text{Jet}}) \tag{2}$$

Error	Blue	Yellow
Uncorrelated errors	ΔP_{fills}	ΔP_{fills}
$\Delta^{\text{stat}}_{\text{Jet}}$	3.1%	2.8%
$\Delta^{A_N}_{\text{profile}}$	0.5%	2.2%
$\Delta^{exptP}_{\text{profile}}$	4.0%	4.1%

Fully correlated errors (between blue and yellow):

$\Delta^{\text{syst}}_{\text{Jet}}$ (2.9%)-this includes background in the jet measurement (2.1%) and the uncertainty of the unpolarized molecular fraction of the jet (2.0%).

The global relative polarization uncertainties for each beam are

$$\begin{aligned}\Delta P_{\text{blue}}/P_{\text{blue}} &= \sqrt{3.1^2 + 0.5^2 + 4.0^2 + 2.9^2} \\ &= \sqrt{5.1^2 \text{ (uncorrelated with yellow)} + 2.9^2 \text{ (fully correlated)}} \\ &= 5.9\%\end{aligned}$$

$$\begin{aligned}\Delta P_{\text{yellow}}/P_{\text{yellow}} &= \sqrt{2.8^2 + 2.2^2 + 4.1^2 + 2.9^2} \\ &= \sqrt{5.4^2 \text{ (uncorrelated with blue)} + 2.9^2 \text{ (fully correlated)}} \\ &= 6.2\%\end{aligned}$$

For the product of the beam polarizations, the global relative uncertainty is

$$\begin{aligned}\Delta P_{\mathrm{blue}} \times P_{\mathrm{yellow}}/(P_{\mathrm{blue}} \times P_{\mathrm{yellow}}) &= \sqrt{5.1^2 + 5.4^2 + (2 \times 2.9)^2} \\ &= 9.4\%.\end{aligned}$$

References

[1] H. Okada et al. Phys. Lett. B638, 450 (2006)

[2] K.O. Eyser et al., RHIC/CAD Accelerator Physics Note Vol.274 (2007)

[3] O. Jinnouchi et al., RHIC/CAD Accelerator Physics Note Vol.171 (2004)

[4] I. Nakagawa and A. Bazilevsky, Presentation slides in RSC meeting March.21,2007. `http://www4.rcf.bnl.gov/ cnipol/pubdocs/Run05Offline/`